

R&D Status and Plan for FPCCD VTX

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Fine pixel CCD (FPCCD) is an option for the sensor used for the ILC vertex detector to reduce the pixel occupancy due to the high background rate near the interaction point. In this paper, we report on the R&D status of FPCCD sensors and the R&D plan for the sensors and the cooling system.

1 Introduction

Fine pixel CCD (FPCCD) is one of the sensor candidates for the vertex detector at ILC experiment [1]. FPCCD vertex detector was proposed [2] as an option compatible with the beam background condition of super-conducting RF technology of the linear collider. The FPCCD sensors have the pixel size as small as $\sim 5 \mu\text{m}$. The sensitive layer is as thin as $\sim 15 \mu\text{m}$ and fully depleted to suppress the number of hit pixels due to charge diffusion. Because of the huge number of the pixels, the pixel occupancy due to pair background can be kept low even if the signal is accumulated for one train of the ILC beam collision. In addition, background rejection can be achieved by the hit cluster shape analysis thanks to the fine pixel size smaller than the sensitive layer thickness. In order to read out the huge number of pixels in the beam-train interval of 200 ms, multi port readout of the FPCCD sensors is indispensable. The horizontal shift registers lie along the beam direction and embedded in the image area. Therefore the number of horizontal (serial) shift is much more than the number of vertical (parallel) shift. This layout gives better radiation immunity than the inverse layout (long parallel shift and short serial shift) like SLD vertex detector.

Our R&D activity for the FPCCD vertex detector has started in 2006. It includes R&D for FPCCD sensors, readout ASICs [3, 4], peripheral electronics such as clock gate drivers, wafer thinning and low mass ladder, cooling system, and simulation study for background rejection [5]. In this paper, R&D status of the sensor is described in section 2, and R&D plan for the cooling system is described in section 3.

2 Sensor R&D

We have developed several types of prototype sensors collaborating with Hamamatsu Photonics. As the first step of the FPCCD sensor R&D, we have developed fully depleted CCDs with a standard pixel size of $24 \mu\text{m}$. It has been demonstrated that the epitaxial layer of these CCDs is fully depleted by using high resistive epitaxial layer of $24 \mu\text{m}$ thickness [6].

Using the same type of the wafer, we have made a FPCCD prototype with the pixel size of $12 \mu\text{m}$ [7]. This prototype has four output nodes and four horizontal shift registers.

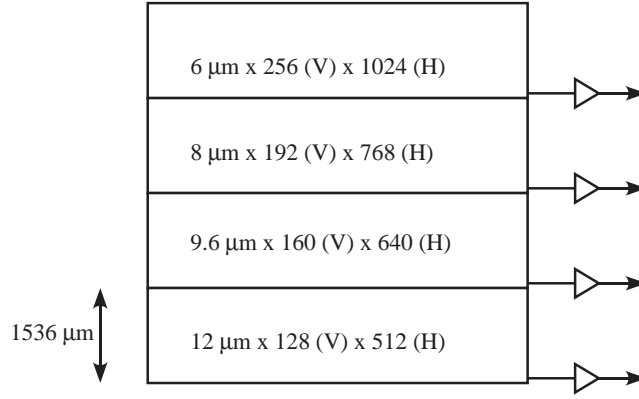


Figure 1: Pixel configuration of a prototype FPCCD sensor in FY2009

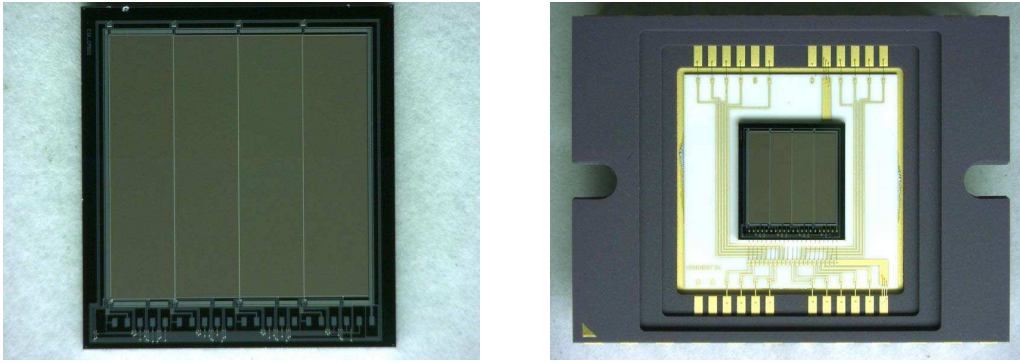


Figure 2: Bare chip (left) and packaged chip (right) of a prototype FPCCD sensor in FY2009

The horizontal registers are embedded in the image area and sensitive to light, as well as to charged particles.

In FY2009, we have fabricated a new prototype of FPCCD sensors with smaller pixel size. Figure 1 shows pixel configuration of the new prototype sensor. It has four types of pixel size, 12, 9.6, 8, and $6\ \mu\text{m}$. The smallest pixel size of $6\ \mu\text{m}$ square is very close to our R&D goal. The chip size (sensitive area) is 6.1 mm square. Pictures of a bare chip and a packaged chip are shown in Figure 2. Bright lines between four areas are horizontal shift registers. Because these horizontal registers are also sensitive, there is no sensitivity gap between four areas.

These prototype chips have just been delivered at the end of March 2010. Detailed study of these chips will be done in FY2010. We would study on S/N ratio, incident angle measurement using the hit cluster shape, spatial resolution, two-track separation, and radiation immunity.

	CO ₂	C ₂ F ₆	C ₃ F ₈
Latent heat at -40°C (J/g)	321	~ 100	~ 110
Triple point ($^{\circ}\text{C}$)	-56.4	-97.2	-160
Critical point ($^{\circ}\text{C}$)	31.1	19.7	71.9

Table 1: Properties of coolant.

3 Cooling system

The estimated power consumption of the FPCCD vertex detector is about 80 W including the sensors and the readout front-end ASICs inside a cryostat. Additional power for peripheral circuits such as clock drivers is also dissipated, but these circuits would be placed outside the cryostat of the vertex detector. The FPCCD vertex detector is expected to be operated at low temperature of $\sim -40^{\circ}\text{C}$ inside the cryostat in order to minimize the effect of radiation damage.

A possible cooling system for the FPCCD vertex detector is flow of cool nitrogen gas. In order to remove heat generated by 80 W power, a flow rate of 3 l/s is necessary with $\Delta T = 20^{\circ}\text{C}$. By using 1 cm diameter gas tube, the gas velocity is as high as 40 m/s. This high-speed gas flow could cause vibration of the ladder. In order to mitigate this risk, we started considering liquid cooling using two-phase CO₂. Because ladders of the FPCCD vertex detector have the major heat source at both ends (output amplifiers of the CCDs and the ASICs), cooling with liquid coolant removing the heat from the ladder ends could be a solution.

Two-phase CO₂ cooling uses latent heat of evaporative liquid CO₂. With two-phase liquid cooling, incoming heat at the evaporator (*ie.* detector) is used for evaporating the liquid rather than raising the temperature. Therefore we can expect almost isothermal cooling along the cooling tube.

Compared to other two-phase coolant such as perfluorocarbon (C_nF_{2n+2}), which is used for example in ATLAS inner detector [8], liquid CO₂ has larger latent heat as shown in Table 1. If we allow 50% evaporation of the liquid CO₂, a flow rate of only 0.5 g/s is necessary. Since CO₂ is circulated under higher pressure (1 MPa at -40°C and 5 MPa at 15°C), volume of the vapor remains smaller than perfluorocarbon. For these reasons, we can use thinner tube for the two-phase CO₂ cooling.

In principle, two-phase cooling can be used in the temperature range between the triple point and the critical point. Since our target temperature of -40°C is close to the triple point of CO₂, it may be challenging to achieve this goal.

In the past, two-phase CO₂ cooling has been used for AMS tracker [9] and LHCb-VELO [10]. It is also proposed for ILD TPC cooling by NIKHEF group. Our group is trying to organize an R&D collaboration for two-phase CO₂ cooling together with ILD TPC group, Belle-II vertex group, and KEK cryogenic group in Japan.

4 Summary

We have developed fully depleted CCDs with standard (24 μm), medium (12 μm), and finally fine (6 μm) pixel size for the FPCCD vertex detector. Detailed study on the FPCCD prototype sensors will be done in FY2010. Cooling system using two-phase CO₂ is an

interesting option for the FPCCD vertex detector because the FPCCD vertex detector has main heat source at the ladder ends. We will start R&D on two-phase CO₂ cooling system collaborating with ILD TPC group, Belle-II vertex group, and KEK cryogenic group in Japan.

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References

- [1] T. Abe *et al.*, ILD Letter of Intent, KEK Report 2009-6.
- [2] Y. Sugimoto, Proceedings of International Linear Collider Workshop LCWS05, Stanford, CA, March 2005, pp.550-554.
- [3] Y. Takubo *et al.*, arXiv:0901.3427[physics.ins-det] (2009).
- [4] K. Itagaki *et al.*, in these proceedings.
- [5] K. Yoshida *et al.*, in these proceedings.
- [6] Y. Sugimoto, Proceedings of International Linear Collider Workshop LCWS2007, DESY, Hamburg, May 2007, 483-485.
- [7] Y. Sugimoto *et al.*, arXiv:0902.2067[physics.ins-det] (2009).
- [8] D. Attree *et al.*, JINST 3:P07003 (2008).
- [9] A.A.M. Delil *et al.*, NLR-TP-2003-001 (2003).
- [10] M. Van Beuzekom *et al.*, PoS(Vertex 2007)009 (2007).